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ABSTRACT

In an attempt to ascertain the facilitating functions of audiovisual between-channel redundancy in information processing, a series of audiovisual experiments alternating auditory and visual as the dominant and redundant channels were conducted. As predicted, results generally supported the between-channel redundancy when input (stimulus) was beyond the human information processing capacity. Data were also interpreted in terms of various theories such as the lower threshold, summation, energy integration, cumulative strength, cuing, and multiple traces of the audiovisual bisensory presentation, implicitly supporting between-channel redundancy. Evidence obtained from the study was also dismetrically opposite to the hypothesis that short-term memory was essentially an auditory system. Based on findings in neurophysiology, it was argued that both short-term memory and long-term memory might very well be integrated systems. Some conflicting evidence was also found on the position of redundant information of one channel in relation to the other channel. Redundant information coinciding with the dominant channel in the beginning was found significantly better than that at the end with the digit-recall tasks, but not with letter-recall tasks. (Author/SW)

Audiovisual Between-Channel Redundancy And Its Effects upon Immediate Recall and Short-Term Memory

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ABSTRACT

In an attempt to ascertain the facilitating functions of audio-visual between-channel redundancy in information processing, a series of audiovisual experiments alternating auditory and visual as the dominant and redundant channels were conducted. As predicted, results generally supported the between-channel redundancy when input (stimulus) was beyond the human information processing capacity. Data were also interpreted in terms of various theories such as the lower threshold, summation, energy integration, cumulative strength, cuing and multiple traces of the audiovisual bisensory presentation, implicitly supporting between-channel redundancy.

Evidence obtained from the study was also diametrically opposite to the hypothesis that short-term memory was essentially an auditory system. Based upon findings in neurophysiology, it was argued that both short-term memory and long-term memory might very well be integrated systems. On the other hand, it might be possible that auditory and visual have separate short-term memory systems.

Some conflicting evidence was also found on the position of redundant information of one channel in relation to the other channel. Redundant information coincided with the dominant channel in the beginning was found significantly better than that at the end with the digit-recall tasks but not with letter-recall tasks. The discrepancy was probably due to the associability of auditory and visual in the letter-recall tasks and the difference between the visual form and the pronunciation of the digit-recall tasks.

Man's information processing capacity (IPC) is finite whereas the information man must process is infinite. Assuming man is an information-seeking animal, searching and processing information for his survival, the disparity between his information processing capability and his need for information processing must bring about a great deal of discomfiture, and more often than not, a sense of helplessness when he is confronting the modern world with an astronomical amount of information to be processed. To further aggravate the situation, man possesses various modality IPC, enormously greater than the capacity of the central nervous system (CNS); eyes, for example, can process a million times and ears a thousand times more information in bits/second than the CNS (Hsia, 1971). Even though the limited capacity of the CNS is a homeostatic function, to block off unnecessary information so as not to overburden the CNS, the inability of processing all the information that can be processed by modality is, indeed, one of the major problem areas in communication and education. Therefore, many theories and concepts have emerged, been explored and examined in a hope to improve IPC, i.e., to maximize the effectiveness of communication defined as a communication process with the least loss of information and error (Hsia, 1971).

Man's basic IPC is biologically and genetically limited. There is absolutely no way of enlarging the IPC of the CNS, that is the delimiting factor of information processing, but there are three basic ways of facilitating information processing: first, encoding message in such a way as to make the information readily processable for modalities and integratable for the CNS, for which Garner (1970) has eloquently expounded; second, reducing noise, interference and unwanted information to such a level that normal processing is unhindered (Shannon & Weaver, 1949) or enhanced (Broadbent, 1958), for on occasion, a little noise forced the communicator and communicatee to be more attentive; and third, employing the redundancy principle (Hsia, 1968a, 1968b, 1969, 1973), in order to facilitate communication.

In his theoretical treatment of redundancy, Hsia (1973) has defined many forms of redundancy: (a) Between-channel redundancy, (BCR) referring to the redundancy between channels, usually auditory and visual channels; (b) dimensional redundancy, referring to the redundancy between information dimension; (c) distributional redundancy, generally referring to the redundancy obtained from the distributional information based upon the frequency of occurrence of every element within a sign system; and (d) sequential redundancy referring to the redundancy obtained from the conditional information which, for example, in a two-letter message, is the dependence of the occurrence of one letter upon the other. Apart from BCR, all other forms of redundancy are within-channel redundancy, dealing with content or substance of communication, and explored in numberous linguistic, psychological books (e.g., Hunter, 1962, Garner 1962, among others). BCR seems to be an important area overlooked so far by many disciplines interested in communication and information processing.

Since man is endowed with a number of information processing modalities connected with afferent (input) and efferent (output) nervous systems, capable of utilizing any and all receptors, sensors and effectors, in transmitting and receiving information. BCR is a key factor in the understanding of human communication which in most cases involves more than one channel or modality. BCR can be simply the similarity of information between auditory and visual, auditory and olfactory, auditory and tactile, and olfactory and so on. In this study BCR is a bivariate model of audiovisual communication. Conceivably BCR is unity when both auditory and visual channels transmit identical information simultaneously; conversely, it is zero when the visual and auditory channels emit completely different information. In the former case, communication facilitation takes place, and in the latter case, communication interference breaks out.

Generally, BCR in this study refers to the similarity of information between auditory and visual. Hsia (1973) has worked out a set of BCR formulas as follows: If A and V are the auditory and visual sets of signs, all a's and v's are the elements in the sets, we have

$$\text{Auditory} = \left\{ a \in A \;\middle|\; a \text{ is the auditory signals} \right\}$$

$$\text{Visual} = \left\{ v \in V \;\middle|\; v \text{ is the visual signs} \right\}$$

Clearly, within each channel, there are a number of signals or signs, i.e.,

$$A = a_i, \quad i = 1, 2, \ldots\ldots, m,$$

$$V = v_j, \quad j = 1, 2, \ldots\ldots\ldots, n.$$

The auditory and visual representations have their information contents as customarily defined in accordance with information theory and probability theory, i.e.,

$$\sum p\ (a_i) = 1, \qquad \text{and} \qquad \sum p\ (v_j) = 1,$$

and the amount of information is defined:

$$H\ (A) = -\sum p\ (a_i) \quad \log \quad p\ (a_i);$$ for the auditory information,

$$H\ (V) = -\sum p\ (v_j) \quad \log \quad p\ (v_j);$$ for the visual information.

Apparently the between-channel redundancy cannot be the sum of the redundancy of the two channels; rather it is based upon the joint information derived from the joint probability. Thus

$$\sum p\ (a_i,\ v_j) = 1$$

and the joint information transmitted by both the auditory and visual channels is

$$H\ (A,V) = -\sum p\ (a_i,\ v_j) \quad \log \quad p\ (a_i,\ v_j)$$

If A and V are identical, i.e., whenever a_i appears, v_j also occurs, then

$$H'\ (A,V) = \log\ m = \log\ n$$

Following precisely the same logic applied to Shannon's redundancy, BCR is thus obtained by the conventional formula

$$BCR = 1 - (\ H(A,V)\ /\ H'(A,V))$$

As can seen readily, BCR is characteristically different from within-channel redundancy. In addition to its versatility in the performance of basic redundancy functions: i.e., to minimize equivocation (information loss) and noise (error) in the communication process, BCR takes no more space or time as other forms of redundancy do, and thereby incurs no more cost in information processing than non-redundancy. Any other form of redundancy pays its price in communication, i.e., the more redundant a message is, the more time or space it needs for information processing, whereas BCR does not.

Current studies have explored many theories in an implicit support of BCR as a superior mode of stimulus presentation. Irrespective of the nomanclature of bisensory, simultaneous, audiovisual and others, generally, the supportive theories for BCR can be categorized into four somewhat overlapping groups: (1) the lower threshold concept; (2) the cuing (and also the preparatory state); (3) the energy integration (including summation, cumulative strength hypotheses); and (4) the multiple-trace.

In a bisensory presentation, BCR was found to have lowered the threshold for information processing and improved auditory threshold with a visual accessary stimulus and vice versa (Treisman, 1964). The lowest threshold was found when accessary stimulus and the signals were simultaneous (Treisman & Howarth, 1959). BCR, on the other hand, provides cues for the whole information processing (Di Vesta & Ingersoll, 1969). It should be particularly true when Ss are either visual attenders or auditory attenders that provides for each according to his likes. In testing the fundamental load-carrying capability of man, Adams and Chambers (1962) have found a net superiority of bisensory over unisensory responding when stimulus events were certain, as either channel provides cues for the other. Visual detectability was improved due to the cuing of auditory signal (Loveless, Brebner & Hamilton, 1970). One channel may sometimes prepare the other channel for information processing (Hintzman & Block, 1971).

When the same information transmitted through two channels and processed by two separate modalities, it is reasonable to assume the neural impulses, chemical as well as electrical, are integrated with added stimulus intensitie across modalities and results in the joint event to be more effectively stronger than either the visual or auditory alone (Bernstein, 1970; Bernstein, Rose & Ashe, 1970). Audiovisual presentation as contrasted to a single modality presentation also provide redundant input based upon the summation theory (Loveless, et al, 1970). The summation theory of audiovisual presentation may also be explicated in terms of cumulative strength (Hintzman & Block, 1971).

The multiple-trace (Hintzman & Block, 1971) hypothesis assumes the multiple strength of memory traces, contrasting to the added strength of the summation or energy integration hypotheses. If information can be processed within a single trace, it is convenient to conclude that the multiple trace of the audiovisual should be unqeustionably better than the single trace of a single modality, provided that there is no interference. Though it is not necessarily correct from a physiological viewpoint, the multiple trace concept is consistent with the notion of lower threshold and cuing, it is however in conflict with the argument that STM is an auditory system.

Laughery and Fell (1969) following a number of studies (Mowbray, 1952, Wickelgren, 1965; Sperling, 1967), have argued that short term memory (STM) is basically an auditory storage system since Ss performed better on auditory items regardless of their mode preference, and incorrectly recalled information had auditory characteristics. Therefore, STM consists of an encoding of the auditory characteristics of the information (Sperling, 1967). It follows that visual information undergoes a transformation prior to its entry to STM.

Whether STM is auditory is a debatable issue. If it is true and since all information must go through STM and bypassing STM seems impossible, then visual information must undergo an auditory transformation in STM before it reaches long term memory (LTM). Such a notion is hardly tenable, for information in LTM is not exclusively formed of auditory codes.

STM, a brief phenomenon presumably taking place before information reaching the CNS, is dependent upon the patterned operations of neuronal circuits running complex reentrant pathways in the cerebral cortex. By synaptic connections, impulses traverse neurons weaving a pattern in space and time, and carry information. That is the dynamic engram as defined by Lashley (Eccles, 1973, P. 176). It is neither auditory, nor visual, nor audiovisual, but an integrated system to synthesize afferent information. If STM is auditory, it stands to reason that by chemical and electrical (mostly chemical) impuleses, LTM may be of auditory as well. There is an absolute lacking of evidence to indicate that LTM is of either auditory or visual. It seems man's extreme dependency upon linguistic communication has misled him to believe that STM might be auditory.

The most probable and plausible answer for the assumption of auditory STM seems to lie in the fact that in the Indo-European language family in which alphabets are used, the error committed in communication is inevitably associated with auditory characteristics. Difficult it may seem to explain why the Chinese cannot understand a Chinese classic being read aloud to him, as he must visualize it in listening before comprehension takes place. But suffice it to say, errors made in verbal communication might be of auditory nature, whereas in visual communication as the case with the Chinese, errors might very well possess visual characteristics.

None of the studies examined have explored the functions and effects in audiovisual information processing as influenced by the redundancy rate of BCR. This study was undertaken to examine the different levels of BCR, and the extent of its facilitating effects on information processing. For an exploratory purpose, the position of audiovisual synchronization of auditory or visual redundant information to the other channel was to be examined in order to ascertain if there was any difference between redundant information at the beginning and the end (termed primacy-redundancy and recency-redundancy respectively).

In the meantime, it was also attempted to explore whether STM was an auditory system rather than an integrated system that could be detected by alternating auditory and visual as the dominant and redundant channel. STM as an auditory system could be supported only when the auditory dominant channel with redundant visual information would be found significantly better than the visual dominant channel with redundant auditory information, while other factors were held constant.

METHOD

A series of audiovisual recall tasks composed of digits and letters (except vowels) with four degrees of BCR at the 25, 50, 75 and 100 per cent levels was tested. All digits and letters used as stimuli were randomly selected individually from a pile of specially made cards. The auditory and visual channels were taken in turn to be the dominant channel and the other the redundant channel to provide redundant information for the dominant channel. Stimuli were a series of 2, 4, 8 and 12 digits or letters. Take the 4-digit or letter trials, for example, if the dominant channel is auditory, the redundant channel is visual, then the auditory channel presented the whole full four letter or four digits, and the visual presented one, two, three, or four digits or four letters, to represent 25, 50, 75 or 100 per cent audiovisual BCR.

The maximum length of digits or letters was set at 12, considering that human information processing capacity was seven plus or minus two (Miller, 1956). In addition to the distinction between the dominant and redundant channels, four more conditions were administered:

(a) The auditory is x/100 redundant (where x is 25, 50 or 75%) of the beginning portion of the visual information, labeled as A = 25/, 50/ or 75/ of V;

(b) The auditory is x/100 redundant of the ending portion of the visual information, labeled as = /25, /50 or /75 of V;

(c) and (d) are the reversal of channels in (a) and (b), labelled as V = 25/, 50/, or 75/ of A; and V = /25, /50 or /75 of A, respectively.

Needless to say, with the 100 % BCR, A =V and V = A. Both (a) and (b) were designated as the auditory-dominant-visual-redundant (ADVR) condition, and (c) and (d) the visual-dominant-auditory-redundant (VDAR) condition.

For (a) and (c), all trials with 25/, 50/ and 75/ labels were designated as the primacy-redundancy condition, indicating the redundant information to be coincided with the beginning portion of the dominant channel. For (b) and (d), all trails with /25, /50 and /75 were designated as the recency-redundancy condition, indicating the redundant information coincided with the ending portion of the dominant channel. For example, if auditory is dominant and visual redundant, for the 8-trial with V = 25/, the audiovisual stimuli were :

A = 85049312

V = 85

and with V = /25:

A = 85049312

V = 12

In all presentations, audiovisual information was synchronized and presented simultaneously. Visual stimuli were projected on the screen synchronized by a Uher tape recorder which automatically controlled both speed and presentation. The speed was based upon the normal conversation speed at about 150 words-per-minute.

Subjects were 24 high-school juniors, each was paid $1.50 per hour plus lunch. A 30-minute training session was staged to familiarize Ss with the immediate recall tests by paper and pencil. Between tasks, for example, of letters and digits, there was a five-minute break in an attempt to break the monotony and to reduce mental fatigue of performing the recall tasks. The visual cue for Ss to begin the trial was a blank slide whereas the auditory cue was a period of silence. The silence period and time for the visual blank depended the length of the stimulus materials.

RESULTS

When the amount of input information was low, the superiority of simultaneous audiovisual presentation was not necessarily manifestable. Only when the input information was above a certain level, audiovisual synchronized stimuli were recalled better than a single channel presentation with the least amount of equivocation (information loss) and noise (error)

(Hsia, 1968a, b). With input stimuli of either 2 or 4 digits, there was predictably no significant difference among different levels of BCR regardless of whether the auditory or visual was the dominant channel or the redundant channel (Table 1).

With the 8-digit input, no significant differences among all levels of BCR was found, but generally the visual-dominant-auditory-redundant (VDAR) was found better than the auditory-dominant-visual-redundant (ADVR). While the stimulus digits increased to 12, there was appreciably significant difference at all different BCR levels. Results shown in Table 1 were exactly as could be predicted: the level of BCR was directly related to the accuracy of recall. The more redundant in BCR, the better recall. Significant differences were found betwen 100% and 25% BCR and between 75% and 25% BCR for all trials and conditions, even though the 50% BCR yielded significant difference only in two of the four comparisons with the 75% BCR.

Table 1 About Here

Comparisons between ADVR and VDAR were significant in the recency-redundancy condition and not significant in the primacy-redundancy condition. In the other words, VDAR-recency was signficantly better than ADVR-recency. It may be assumed that the visual channel as the dominant channel was superior to the auditory as the dominant channel when the redundant information was presented at the terminal of the dominant channel.

Data in Table 1 might not be conclusive to establish the visual as a better channel acting as the dominant channel. It throws doubts on the hypothesis that the auditory is the dominant channel for human information processing as argued by a host of experimentors, to which we shall return later on.

In comparison between primacy-redundancy and recency-redundancy for the 12-digital trials, significant difference was found beyond the .01 level whereas for the 8-digital trials, no significant difference was detected. Again, it might not be authoritatively concluded to consider primacy-redundancy more effective than recency-redundancy; however, it is safe to assume that primacy-redundancy facilitated information processing when input stimuli had a high amount of information. No significant differences were found for the 2 and 4-digit trials in ADVR and VDAR or primacy-redundancy and recency-redundancy comparison which therefore was omitted from Figure 1.

Figure 1 About Here

In the letter-recall tasks, the BCR effect was neatly split between the VDAR and ADVR conditions: BCR made no significant contribution to the effectiveness of communication under the VDAR condition; but on the other hand, it was unquestionably an effective means for the improvement of information processing under the ADVR condition. Of many available explanations, the more plausible one is: the visual dominant channel with auditory redundant information provided Ss with better rehearsal or back-scanning, and therefore, there was no room for BCR to improve any more, as can be readily seen that there was no significant difference between 100% BCR ($\bar{X}$ = 11) and other BCRs. In ADVR, however, the rehearsal or back-scanning was limited to the portion of visual information; therefore, the higher BCR, the better result was for the recall tasks. Once more, no significant differences existed among all conditions and treatments for the 2- and 4-leter recall tasks (Figure 2).

Table 2 About Here

In the letter-recall tasks, some conflicting evidence concerning primacy-redundancy and recency-redundancy was found, as there was no difference whatever between differently positioned redundant information. Comparisons between VDAR and ADVR was found significant across all levels of BCR, indicating that the visual presentation with auditory redundant information was better than the auditory presentation with visual redundant information and that the results support the findings of the digital tasks. This evidence raises serious question about the hypothesis on STM being an auditory system.

If STM is auditory, then ADVR should have been a better performer than VDAR; for ADVR transmits auditory information to be recalled in its entirety and thus involves no visual-to-auditory transformation whereas VDAR which transmits visual information in its entirety has to go through some transformation, and is therefore prone to the intrusion of noise and also equivocation. In this study, however, VDAR was found invariably better than ADVR. It seems to indicate that STM is hardly an auditory system, nor must information prior to its entry to STM go through an visual-to-auditory or auditory-to-visual transformation. More likely, STM is an integrated system, taking information from many different modalities, rather than oriented to a particular modality.

Figure 2 About Here

Discussion

BCR in the present study seems to have established its usefulness in information processing, whether it is based upon the hypotheses of energy integration (summation and cumulative strength), cuing, multiple traces, or lower threshold. Each explains certain aspects of BCR functions, but none describe BCR completely. Possible but not absolutely certain, BCR possesses the combinational functions of multiple traces, cuing and summation so that information processing was facilitated. To comprehend all the phenomena of multiple traces, cuing, energy integration, summation and lower threshold hypotheses of bisensory information processing, it is necessary to delve into psycho-physiological and neurological studies, that however is beyond the scope of this paper.

Within a limited range, man has been found to be capable of processing simultaneous messages from different modalities (Mowbray & Gebhard, 1961). In reaction time studies, multiple-traces, cuing and summation can be studied; however, of all these studies, the present study included, none can solve all problems in modality information processing. Unless the brain can be studied as the heart, opened, removed and kept alive, modality studies may remain a speculative adventure, because we can only manipulate input (stimulus), examine output (response), and then speculate to the best of our knowledge about what has happened inside the black box. The only non-speculative thing about BCR is: BCR does provide for the auditory or visual attenders whatever they prefer as found by Ingersoll and Di Vesta (1972).

One word of caution is in order: Despite the adaptability of BCR to theoretical concepts supporting the superiority of audovisual simultaneous presentation, only slight dissynchronization or time-lag between auditory and visual is likely to cause bisensory interference instead of facilitation in information processing. BCR is also extremely time-consuming in its preparation, particularly for its synchronization. From a pragmatic viewpoint, BCR is conceptually a simple device to increase the effectiveness of communication. Its implication in teaching-learning and communication is almost self-explanatory. From a theoretical viewpoint, BCR has perhaps pointed out that man's memory systems are of neither visual, nor auditory, but integrated, but we have no idea how it is integrated. Therefore, the superiority of VDAR over ADVR may very well be due to the fact that VDAR presented a more flexible rehearsal strategy as found by Sherman and Turvey (1969) rather than that STM is a visual system. It is entirely possible that there are two or more separate memory systems as indicated by Murdock and Walker (1969) and Nilssen (1973); auditory and visual information is handled by different memory systems.

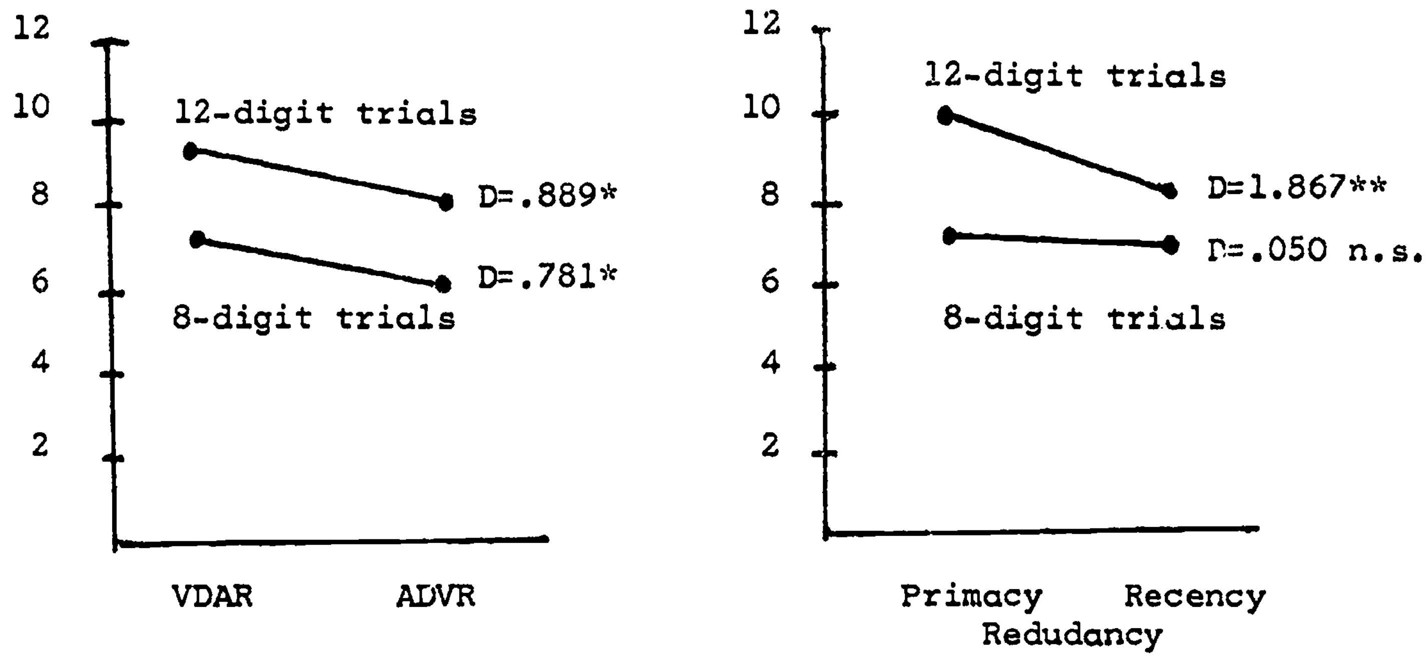
The conflicting findings on primacy-redundancy and recency-redundancy has no simple explanation. Why primacy-redundancy effects were found only in the digital recall task but not in the letter-recall task raises many questions for which the present study has no answer based upon evidence so far obtained. Probably letters were more integratable in either auditory or visual form than digits when entering STM. It is plausible but not proven that the drastic difference in auditory and visual presentation of digits, for example, 3 in the visual but "three" in the auditory, may account for the effect under the primacy-redundancy condition in the digital tasks. Under the recency condition, the redundant channel might have introduce interference when portion of the redundant information was superimposed on the middle of the dominant channel. Undertandably, this study raised more questions than solutions it set out to provide.

Table 1

Means* of Audiovisual Between-Channel Redundancy of Four Levels (25, 50, 75 and 100%) in Digital Recall Tasks with the Auditory and Visual as the Dominant and Redundant Channels

	No. of Digits Auditory	Visual	2	4	8	12
	100	100	1.898	3.761	7.478	10.159
	75/	100		3.671	7.761	10.198
	50/	100	1.988	3.943	7.295	10.114
V	25/	100		3.488	7.386	9.580
D A	/75	100		3.671	7.614	9.614
R	/50	100	2.000	4.000	7.114	8.512
	/25	100		3.475	7.114	8.398
	100	75/		3.692	6.559	10.606
	100	50/	2.000	3.591	6.468	10.178
A	100	25/		3.796	6.534	8.682
D V	100	/75		3.568	6.671	8.556
R	100	/50	1.977	3.955	6.511	6.613
	100	/25		3.409	6.682	6.466

* Composite grand means for 10 trials.



** $p < .01$; * $p < .05$; n.s. Not significant

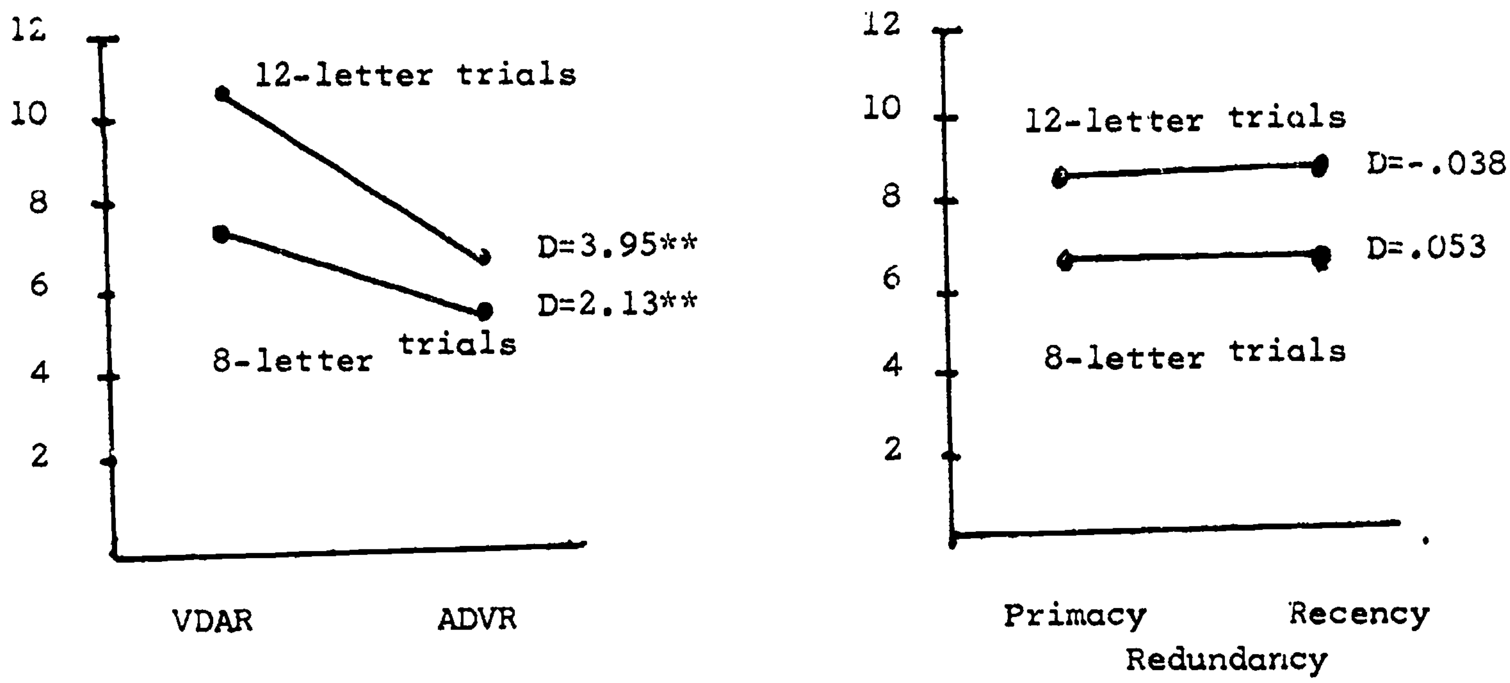
Figure 1 Comparisons between VDAR and ADVR and between Primacy-Redundancy and Recency-Redundancy in 8- and 12-digital Recall Tasks with Audiovisual Between-Channel Redundancy

Table 2

Means of Audiovisual Between-Channel Redundancy of Four Levels (25, 50, 75 and 100%) in Letter-Recall Tasks with the Auditory and Visual as the Dominant and Redundant Ch

No. of Letters Auditory	Visual	2	4	8	12
100	100	1.977	3.829	7.329	11.000
75/	100		3.887	7.602	10.875
50/	100	2.000	3.773	7.557	10.500
25/	100		3.909	7.727	10.306
/75	100		3.989	7.818	10.853
/50	100	1.965	3.750	7.580	10.704
/25	100		3.796	7.671	10.807
100	75/		3.886	6.534	9.352
100	50/	2.000	3.841	5.329	6.625
100	25/		3.943	4.977	5.170
100	/75		3.796	5.989	7.836
100	/50	2.000	3.762	5.421	6.546
100	/25		3.829	4.875	5.307

* Grand means for 10 trials.



** $p < .01$

Figure 2 Comparisons between VDAR and ADVR and between Primacy-redundancy and Recency-redundancy in 8- and 12-letter Recall Tasks with Audiovisual Between Channel Redundancy

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